PAP-639

THE PLANNING AND DESIGN OF A PROTOTYPE PUMPING PLANT USING ARCHIMEDES SCREW PUMPS

October 1993

by

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Presented at the USCID/Bureau of Reclamation
1993 Seminar
Sacramento, California

THE PLANNING AND DESIGN OF A PROTOTYPE PUMPING PLANT USING ARCHIMEDES SCREW PUMPS

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I. INTRODUCTION

Red Bluff Diversion Dam is located near Red Bluff, California, on the Sacramento River. The diversion dam, constructed in the mid-1960's, delivers a maximum discharge of 3030 ft^3/s to the Tehama-Colusa and Corning Canals.

Salmon passage has always been a concern at Red Bluff Diversion Dam. The original construction included fish ladders on each dam abutment, but adult salmon have had difficulty locating the ladders to continue their upstream migration. These fish are detained on the downstream side of the dam until it is too late for them to spawn. There are also indications that juvenile, out migrating, salmon that pass under the gates and through the spillway stilling basin are subject to increased predation.

Numbers of migrating salmon in the Sacramento River are declining. A subspecies, the Winter Run Chinook, is listed as "threatened", and may soon be listed as "endangered."

In an attempt to assist salmon migrations past the dam, Reclamation began raising all of the dam gates out of the water during the winter months of the year beginning in 1986. With the gates out of the water, fish can migrate past the dam in both directions essentially as if the dam did not exist. The gates are currently out of the water from November through April. In the near future the gates up period will be extended to October through May. Reclamation is unable to meet its contracted water deliveries in the Tehama-Colusa Canal during the gates up period. Temporary pumping facilities have been used to date to meet the reduced winter water demands.

To address long term solutions to the fish passage problem Reclamation initiated the Red Bluff Diversion Dam Fish Passage Program. In the initial phase of the program numerous long term solutions were studied (Reclamation, 1991). From this study Reclamation identified two primary concepts for further evaluation. One consists of modifying or replacing the existing fish ladders at

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the dam. This concept would allow maintenance of gravity diversion. The alternative concept would supply flow by pumping through much if not all of the year. Gravity diversion might continue to be used for a month or two during high demand periods. Depending on the duration of pumping, a permanent plant would have a discharge capacity of 2,000 to 3,000 ft^3/s.

A louver system was included in the original canal design to exclude fish from the diverted flow. In 1990 the louvers were replaced by an angled drum screen structure. If a pumping facility is used it would lift water with entrained fish to the canal. The drum screen structure would continue to be used to return diverted fish to the river.

To test the fish passage capabilities of selected pumps and develop design features for a permanent pumping plant, Reclamation is planning to build a pilot or demonstration facility, the Red Bluff Pilot Pumping Plant (RBPPP). A contract will be awarded for construction of the RBPPP on September 30, 1993. The RBPPP will begin operation by January 1, 1995.

Coordination between Reclamation, the US Fish and Wildlife Service, the National Marine Fisheries Service, and California Department of Fish and Game was critical to the project development. This project required a sizeable research and design effort. This paper presents a project overview which focuses on the design and features of the facility.

II. PUMPS

Based on review of the literature and discussion with the fisheries agencies, two pump designs were selected for evaluation:

1. Rotating cylinder Archimedes screw pump - With this pump design the cylinder and the internal helical flights are a single, integral unit. The cylinder is supported by lower self-aligning rollers which take most of the radial load, and by a spherical roller bearing at the top end which takes all of the thrust load and part of the radial load. The motor drive is at the top of the unit. The lower rollers may be positioned between a quarter and midway up the cylinder. It is anticipated that pumps with the largest available cylinder (10 ft diameter) would be included in a permanent pumping facility. Two 10-ft-diameter units will be evaluated in the RBPPP. Rotational speeds may be as high as 28 revolutions per minute (r/min). The discharge capacity of a 10-ft-diameter, three-flight pump, set at a 38° angle, rotating at 28 r/min, is approximately 100 ft^3/s. Both pump performance and the fish passage characteristics of the pump are likely dependent on pump speed. Thus both units will include variable speed drives.

Only limited studies have been conducted evaluating fish passage through a rotating cylinder Archimedes screw pump. These studies, conducted by Pacific Gas and Electric Company (PG&E) and the California Department of Fish and Game (Week et al., 1989), evaluated possible use of a rotating cylinder Archimedes pump as part of a fish bypass for PG&E's Potter Valley intake. With modifications, a 30-inch-diameter pump was successful in passing 1.5- and 8.0-inch steelhead, 5.0-inch coho, and 1.5- and 3.0-inch chinook salmon with no mortalities.

All indications are that this pump, with its low operating speed and absence of pressure differentials, cavitation, and severe turbulence, will minimize fish mortalities and fish disorientation.

2. Screw/centrifugal pump - This is a centrifugal pump with a shrouded screw impeller. The flow enters the impeller at a low angle and passes through a fairly smooth impeller chamber with minimized boundary shear. The pump operates at a relatively high speed (as compared to the Archimedes screw pumps) with previous successful low mortality operation documented at pump speeds of 400 to 600 r/min. Pump discharge and speed are dependent on lift. To lift 100 ft^3/s, 20 ft vertical; a 42-inch pump driven at approximately 400 r/min is required. Twenty-eight-inch pumps are the largest units readily available. A 42-inch pump will be designed and manufactured for the RBPPP. This pump, which can be constructed in even larger sizes, is more compact than the Archimedes pump. Thus the screw/centrifugal pump offers the potential for significant structure and capital cost reduction. As with the Archimedes screw pump, a variable speed drive will be included to allow evaluation of pump operating characteristics and fish passage as a function of pump speed.

Several tests have been conducted to evaluate fish passage through screw/centrifugal pumps (Alden Research Laboratory, 1981; Patrick, 1982). Fish passage performance appears to vary with species, life stage, and pump speed. Although not addressed in the screw/centrifugal pump evaluations, the size of fish relative to pump size (small fish passing through a large pump have a better chance) is also a likely factor. Note that larger lifts will typically require higher pump speeds which may have an increased potential for adverse fisheries effects. Previous tests show mortalities of 80 percent for alewife and herring and 20 percent for heavy densities of up to 8-in-long pike, alewife, and smelt (with a 944 r/min pump speed). Numerous runs have shown near zero mortalities. Limited fish passage work has been done with salmonids. Patrick (1982) saw 96 percent, 48-hour survival when passing 7-in-long rainbow trout through a 5-in pump. Concern has been expressed that even though mortalities may be low, disorientation of the fish resulting from pump passage may cause the fish to be susceptible to predation.

The screw/centrifugal pump is designed to pass solid materials with little or no damage. Passageways are, however, much smaller than those in the 10-ft-diameter Archimedes screw pump. It appears that the screw/centrifugal pump would be more susceptible to fouling with large debris than the Archimedes screw pump. Thus debris handling, as well as fish passage, will be critical features evaluated with the screw/centrifugal pump.

Because of the cost and efficiency advantages that the screw/centrifugal pump offers, and because of its relatively small cost as compared to the overall cost of the pilot facility, one screw/centrifugal pump will be evaluated in the pilot facility.

III. STRUCTURES

The RBPPP includes the following structures:

- Intake Structure;
- Pump Bay Structure;
- Fish Screen Structure, and;
- Evaluation Facility.

The layout of the RBPPP is shown in Figure 1.

A. Intake Structure

The intake structure is located in the Sacramento River, just downstream from the right bank fish ladder entrance. The structure consists of a concrete headwall with four pump intakes. Trashracks are included on the structure to prevent large trash from entering the pump intakes. The four pump intakes consist of openings in the headwall for four 48-inch diameter suction tubes which convey water to the pumps. The entrances are designed to accommodate interchangeable, metal intake transitions. The initial intake transition that will be tested is a symmetrical bellmouth.

River flow conditions in the vicinity of the intake structure are extremely important and were a governing factor in the design of the structure. We attempted to orient the structure in the river so that a sweeping velocity in the downstream direction was maintained along the face of the intake structure under all river flow conditions and for all pumping plant operations. Sweeping flows are desirable to keep juvenile salmon moving past the structure in the hopes of minimizing the numbers of salmon that are pulled into the pump intakes. Sweeping flow also will sluice debris and sediment past the site thus reducing maintenance demands. The intake structure is set in the river such that it converges on the flow thus helping to sustain a strong sweeping

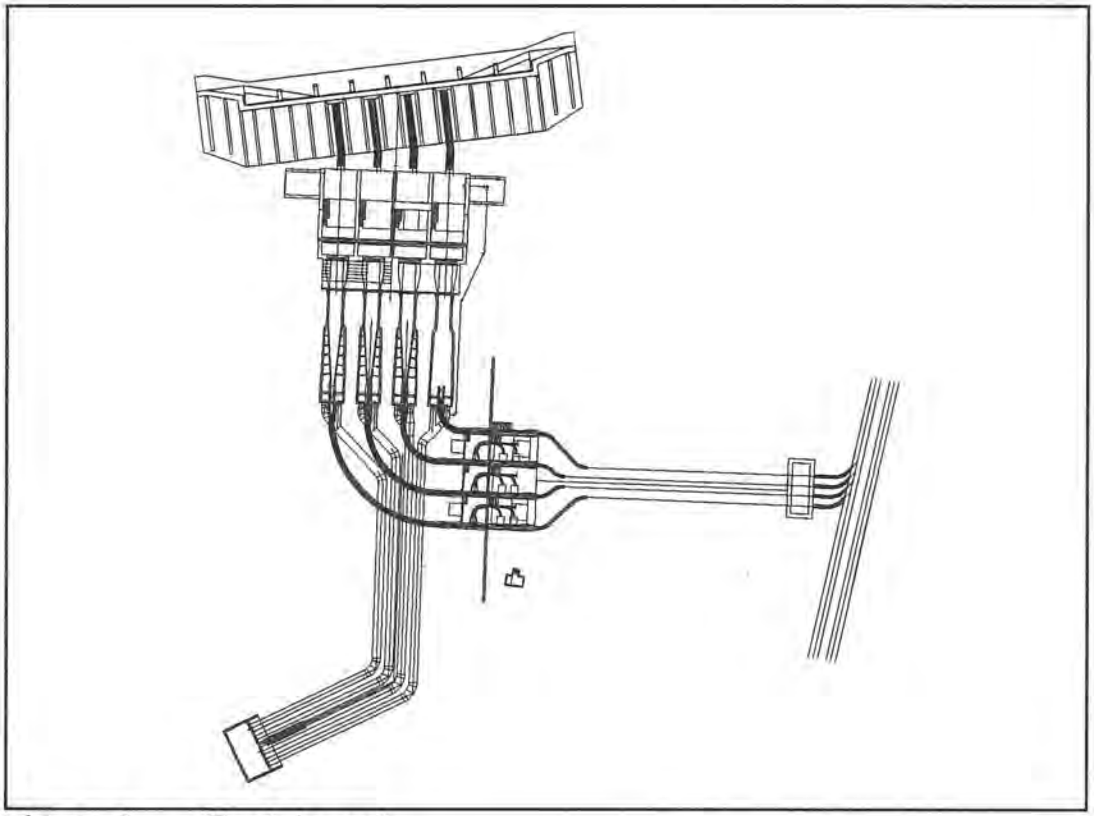

Figure 1. - Plant Layout

action.

Laboratory model studies have indicated that sediment deposition (as a bar) strongly influences sweeping flows past the intake. The river intake will not produce the desired sweeping velocities for all anticipated conditions. However, the model study shows that proper sweeping velocities can be generated and maintained if sediment deposits upstream of the dam are removed or if the flow distribution passing the dam is manipulated (forcing flow to the right).

Large-scale concrete chamfers are designed into the headwall at each end to provide for smooth river flow transitions into and out of the structure. These are designed to help maintain sweeping flows and to minimize eddies and reverse currents in the vicinity of the structure. Any eddies, backwater, or flow reversals have the potential of becoming predator habitat, which is always a major concern with any in-river construction.

The Intake Structure is shown in Figure 2.

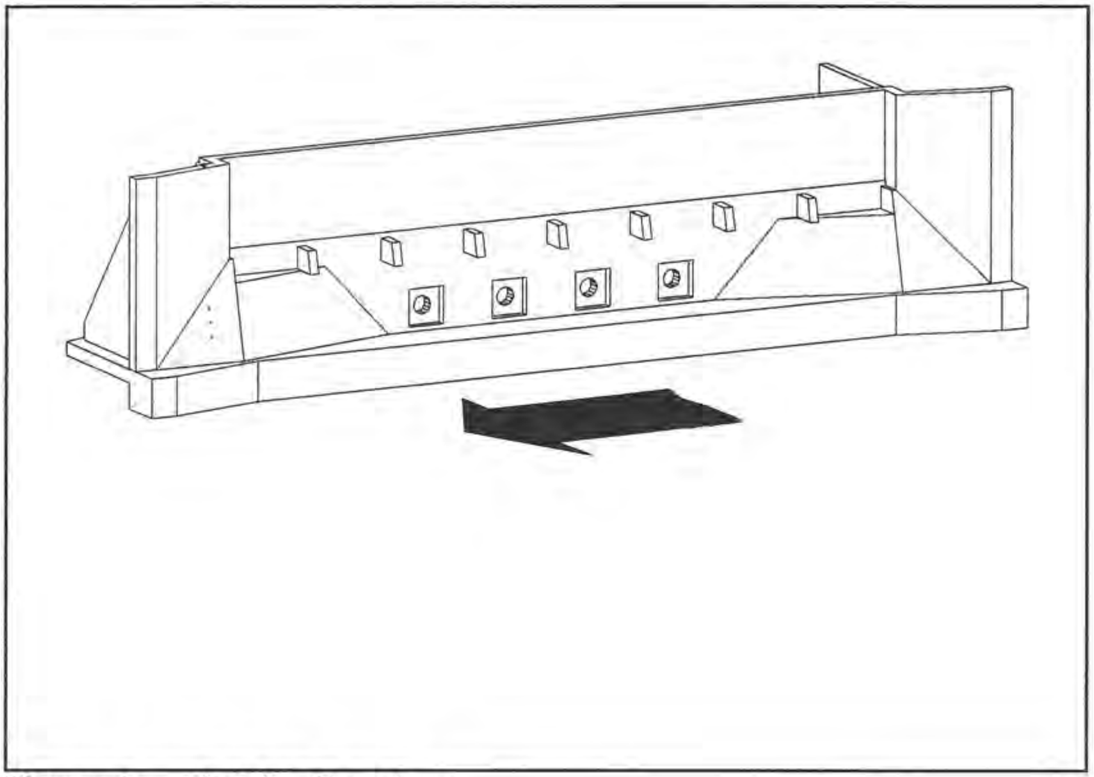

Figure 2. - Intake Structure

B. Pump Bay Structure

The pump bay structure is designed to accommodate the pumps. Three pumps will be installed and tested initially. Two of the pumps will be Archimedes Screw pumps and the third will be a helical screw pump. The pump bay structure is designed to accommodate a future fourth pump of either kind.

The pumps will deliver approximately 100 ft^3/s each to the screening facility structure.

The screw/centrifugal pump must be placed below tailwater level for adequate pump submergence and priming. Thus the screw/centrifugal pump must be placed in a dry well. The self-aligning rollers which support the lower barrel of the Archimedes pump must be kept dry. Therefore, because of varying river stage the Archimedes pump must also be placed in a dry well. The pump bay structure is designed to prevent flooding of the pumps for river discharges up to elevation 267.0 feet.

Isolating the Archimedes pumps from the river requires the development of a large diameter seal between the rotating cylinder of the pump and the fixed suction tube. It is expected that this seal design will require refinement during the RBPPP investigation.

Use of a screw/centrifugal pump would not require development of a large seal.

A section through the pump bay structure showing the Archimedes Screw Pump is presented in Figure 3. A section through the pump bay structure showing the Screw/Centrifugal Pump is presented in Figure 4.

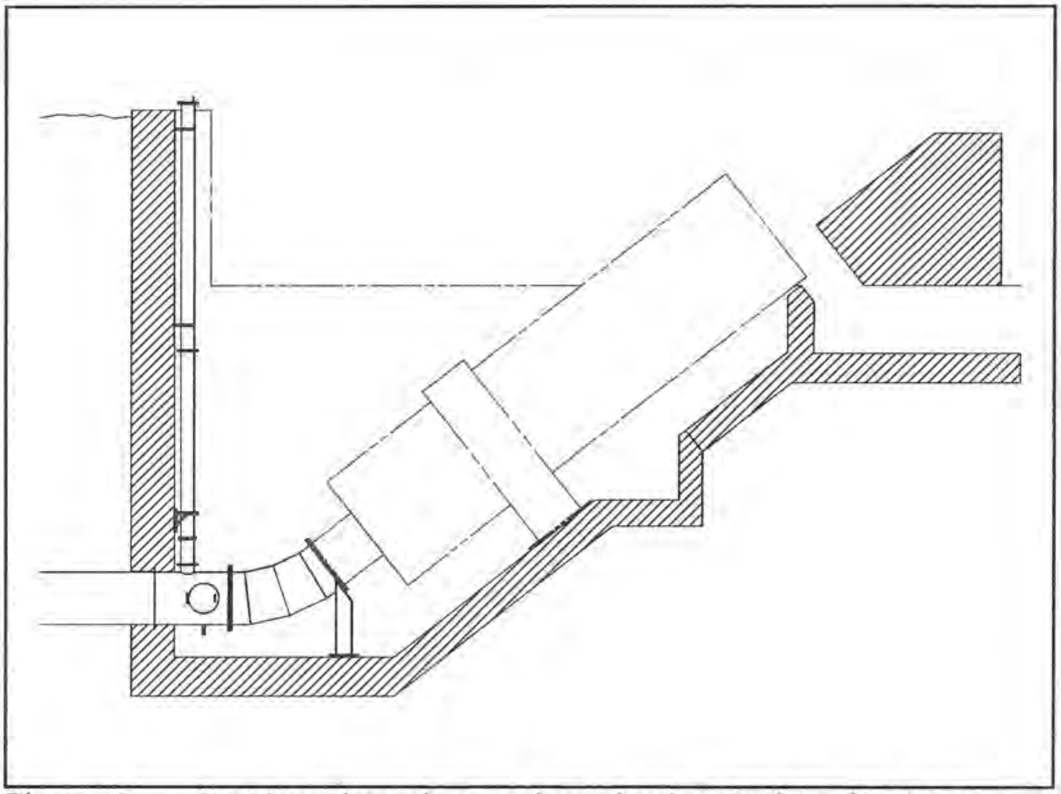

Figure 3. - Section through pump bay showing Archimedes Screw Pump

C. Screening Facility Structure

The screening facility structure receives water from the pumps and utilizes a pair of screens for each pump bay to separate fish from the water to be delivered to the Tehama-Colusa Canal. The screens are flat panel wedge-wire arranged in a labyrinth configuration. About 90% of the pumped water will pass through the screens and will be delivered to the canal. The remaining 10% of the flow, which contains the fish, will be passed to the juvenile evaluation facility.

D. Juvenile Evaluation Facility

Upon entering the juvenile evaluation facility, the fish are directed into holding tanks where they can be monitored for injury,

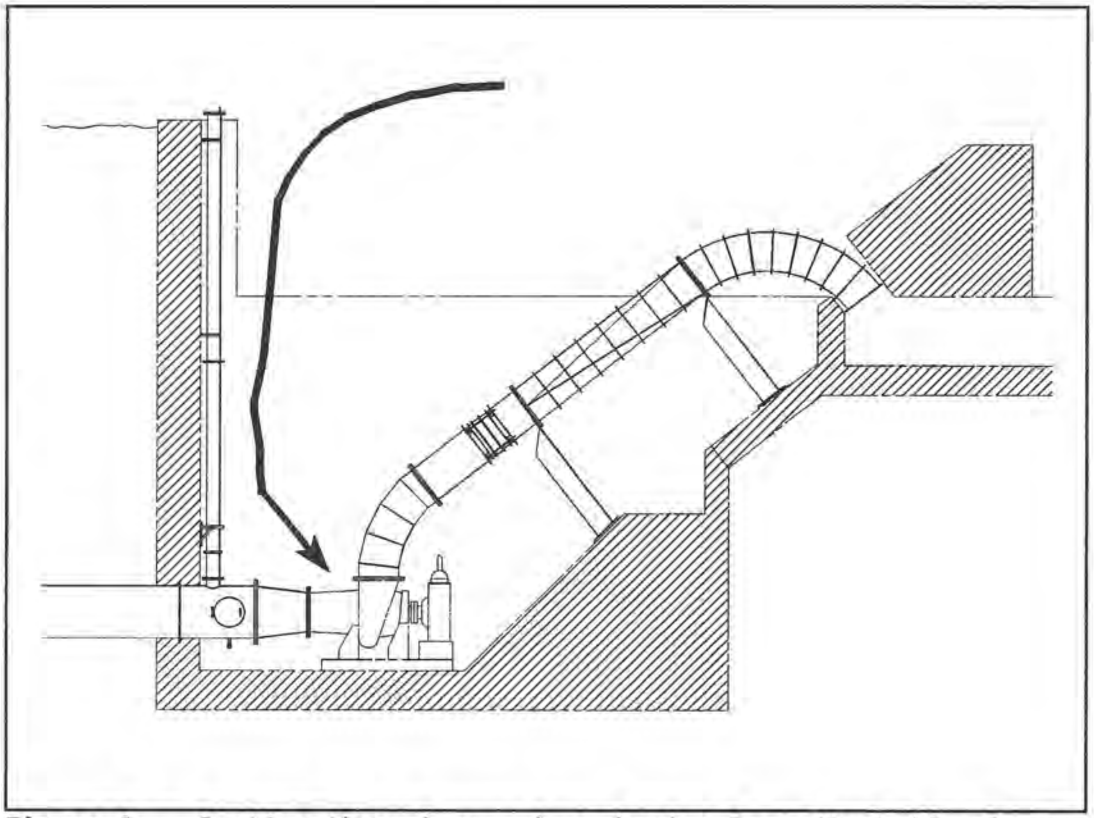

Figure 4. - Section through pump bay showing Screw/Centrifugal pump

mortality, and or disorientation resulting from pump passage. The fish may also be released directly into the bypass where they will be transported back to the river.

IV. Evaluation

Biological and engineering evaluation of the facility will extend from January 1995 through December 1998. The evaluation phase will include a shakedown period, a 2-year aggressive evaluation and experimentation period, followed by an extended evaluation of the operation of the recommended structure.

Biological evaluation will include:

1. Determination of fish mortalities associated with pump passage as a function of pump speed and seasonal variations in the fishery and water quality (including temperature).

2. Determination of the increased potential for predation as associated with pump passage.

3. Behavioral evaluation of fish approaching and entering the pump intakes. Attempts will be made to emphasize observed avoidance behavior in an attempt to reduce fish entrainment.

4. Evaluation of predator attraction to the pumping plant and its associated facilities and development of a means to reduce predation.

5. Determination of whether the pumping plant has adverse influence on in-river fish migration.

Engineering evaluation will include:

1. Development of the in-river pumping plant intake including determining sweeping flow velocity magnitudes required to guide fish and sluice debris and sediment past the structure.

2. Development of a trashrack structure design that will sustain sweeping flows through the pumping plant sump, that will handle debris and sediment with minimum maintenance, and that could possibly be used to louver fish away from the pump intakes.

3. Evaluation of pump performance as a function of pump speed and development of pump features that minimize operation and maintenance demands.

4. Development of features for the permanent pumping installation that will minimize capital, operation, and maintenance costs.

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